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JUN 77 D DENTZ, I LOWE, S TURNER, R BELT DAAB07-77-C-0375

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Manufacturing Methods and Technology
Engineering for Neodymium Doped YAG Laser Rods

D. Dentz
I. Lowe
S. Turner
R. Belt

First Quarterly Progress Report
March 1, 1977 to May 31, 1977

Contract No. DAAB07-77-C-0375

The objective of this program is to develop the production engineering techniq[illegible] for multiple rod fabrication of Nd:YAG laser materials to a set of spec[illegible]ons typical of a system rod.

ABSTRACT

The planning of the effort and initial work on the batch fabrication of Nd:YAG laser rods were accomplished. The primary objectives of the work were to complete design of the polishing fixture and select an initial manufacturing process. The polishing fixture designed is capable of holding sixteen laser rods within the required tolerances during the grinding and polishing process. The polishing process selected, based upon prior work, consists of three separate grinding steps and two polishing steps. All work is to be accomplished at a single work station.

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PURPOSE

The purpose of this production engineering program is to develop the mechanical and optical processes for multiple rod fabrication of neodymium doped YAG laser material. Control of quality is to be obtained through test procedures designed to meet the specifications of a typical system rod.

1.0 INTRODUCTION

The Nd:YAG solid state crystal laser is the most widely used and studied device for present and future military applications. Since its discovery in 1964[1], Nd:YAG has proved to be a nearly ideal engineering material and increased rod requirements are a certainty for all service branches. Two persistent production problems have slowed the more extensive use of Nd:YAG in the form of low cost rods. The first of these was the availability of high purity and optically perfect rough boules capable of good rod yields. In 1970 the Army addressed itself to this area and a successful program was completed.[2] The second problem involves the fabrication of laser rods using techniques of batch processing in place of unit operations.

During the period 1970-1975, Nd:YAG laser devices experienced a period of advanced engineering development. At this stage the normal rod usage attained a maximum of 1-5 rods/month. Laboratory procedures for fabrication were developed and all operations were done by hand on each rod. At the present time the Army laser programs include items such as the AN-VVG-1 laser rangefinder, the GLLD locator designator, the AN/VAS-8 designator tracker, proposed laser tank rangefinders, and the AN-GVS-5 hand held rangefinder. Similar programs and expanded plans are forecast for the Navy and Air Force during the period 1976-1981. Thus the production requirements of Nd:YAG are rapidly approaching 100-300/month and by 1979 could easily reach 300-500/month. Thus it becomes imperative to develop procedures for laser rod fabrication which are more amenable for increased production yields per man hour.

The purpose of this production engineering program is to devise the mechanical and optical processes for multiple rod fabrication of Nd:YAG

laser material. A secondary objective is the control of quality through test procedures designed to meet the specifications of a typical system rod. The program builds upon currently existing techniques for single rod fabrication to attain the design goal of twelve rods per eight hour day. During this process particular attention must be given to rod parameters such as flatness, parallelism, perpendicularity and surface finish. Control to within the required tolerances can be achieved by directing efforts at proper tooling and process design.

2.0 DEVICE

The input material to the program is single crystal neodymium doped yttrium aluminum garnet (YAG). The dopant level is to be in the range of 1.0 to 1.3 atomic weight percent neodymium. From the single crystal boule, areas are selected which are of high optical quality. These areas are used to core drill rough rods which are subsequently centerless ground and sized in preparation for the final polishing operation.

The laser rod to be produced is a 4.27 millimeter diameter by 43 millimeter long rod. The outside diameter is to be of a rough ground finish. Starting with rods of material having rough ground end faces, finished laser rods having a flatness within 0.2 wavelength of sodium light and a surface finish better than 20-5 per MIL-O-13830 are to be produced. The end faces are to be parallel to within 20 seconds of arc and perpendicular to the rod axis within 5 minutes of arc. (See Appendix for complete rod specifications)

The process to be used in polishing the end faces will utilize block mounted rods. These blocks of rods will be handworked using rotating laps and a free abrasive slurry. Grit sizes are successively reduced in processing to achieve the final finish required. During these operations the

critical parameters of flatness, parallelism, perpendicularity and surface finish will be continually monitored.

3.0 FIXTURING AND TOOLING

One critical aspect of this program is the design of the necessary fixturing and tooling for batch fabrication of rods. The design chosen must be capable of producing rods to within the required tolerances at a minimum rate of twelve per eight hour day. The following sections discuss the fixturing and tooling associated with the fabrication operation as well as some of the special items associated with the testing required.

3.1 Polishing Fixture

The polishing fixture designed for this program (Figure 1) has evolved from other fixtures of similar design. The fixture is designed to hold sixteen rods and is toleranced such that the rod axes are held to within one minute of perpendicularity to the block end face and parallel to one another within one minute. The quantity of sixteen rods was chosen to provide for symmetry of design as well as to allow for the possibility of some losses during the polishing operation.

An aluminum cover was incorporated in the design to protect the finished first ends, while grinding and polishing the second end. The cover is designed to mask the finished rods, while leaving the polishing feet exposed to be used as a reference plane while working on the second side.

3.2 Work Station

The work table (Figure 2) is of a very basic design and has been used extensively for single rod fabrication. It consists of a vertical mounted shaft, tapered at the top end to accept the different types of polishing and grinding tools. A pully is attached at the bottom end, which is connected to a variable drive motor by a belt. The use of a variable

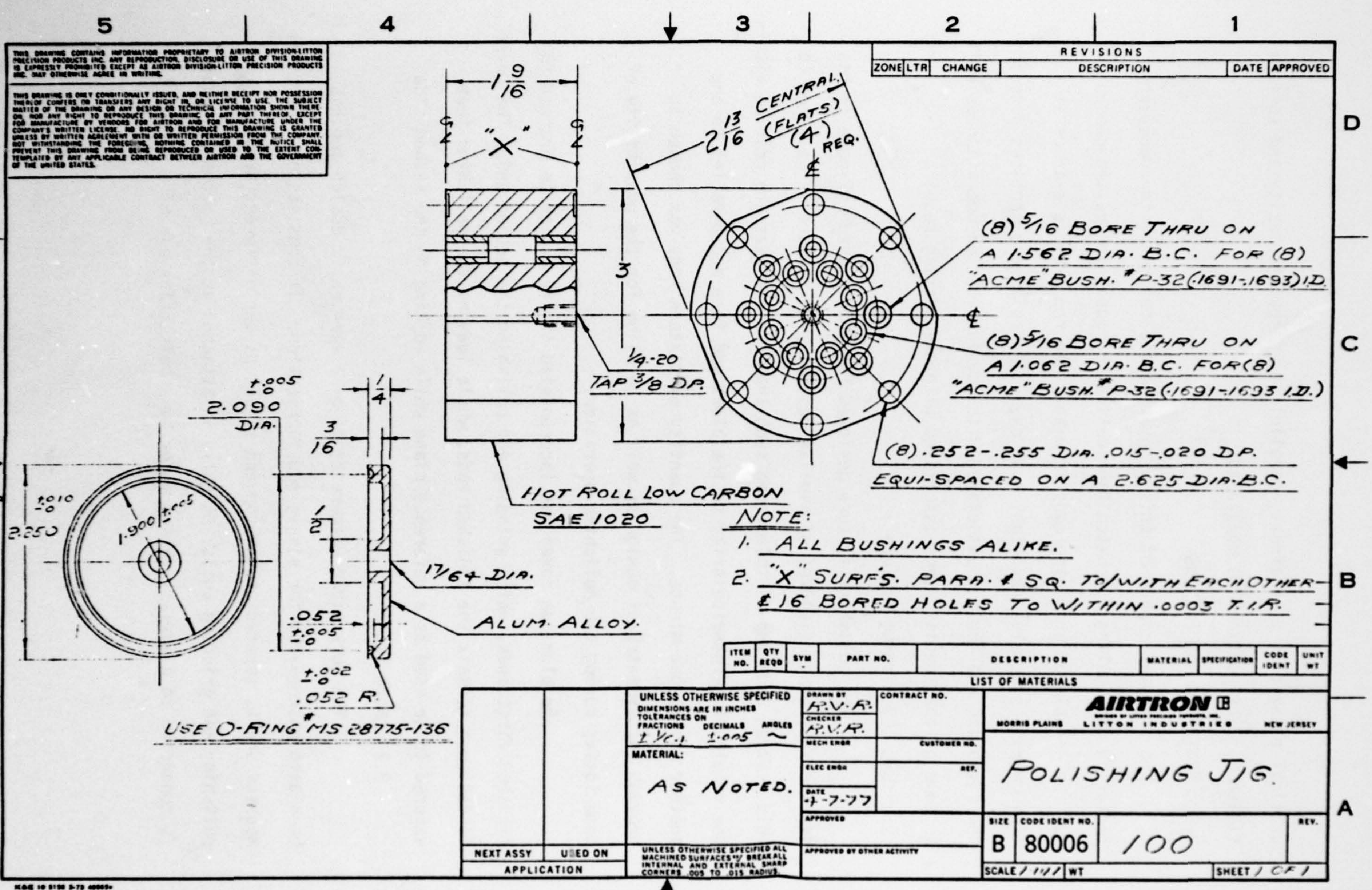


Figure 1 Polishing Jig

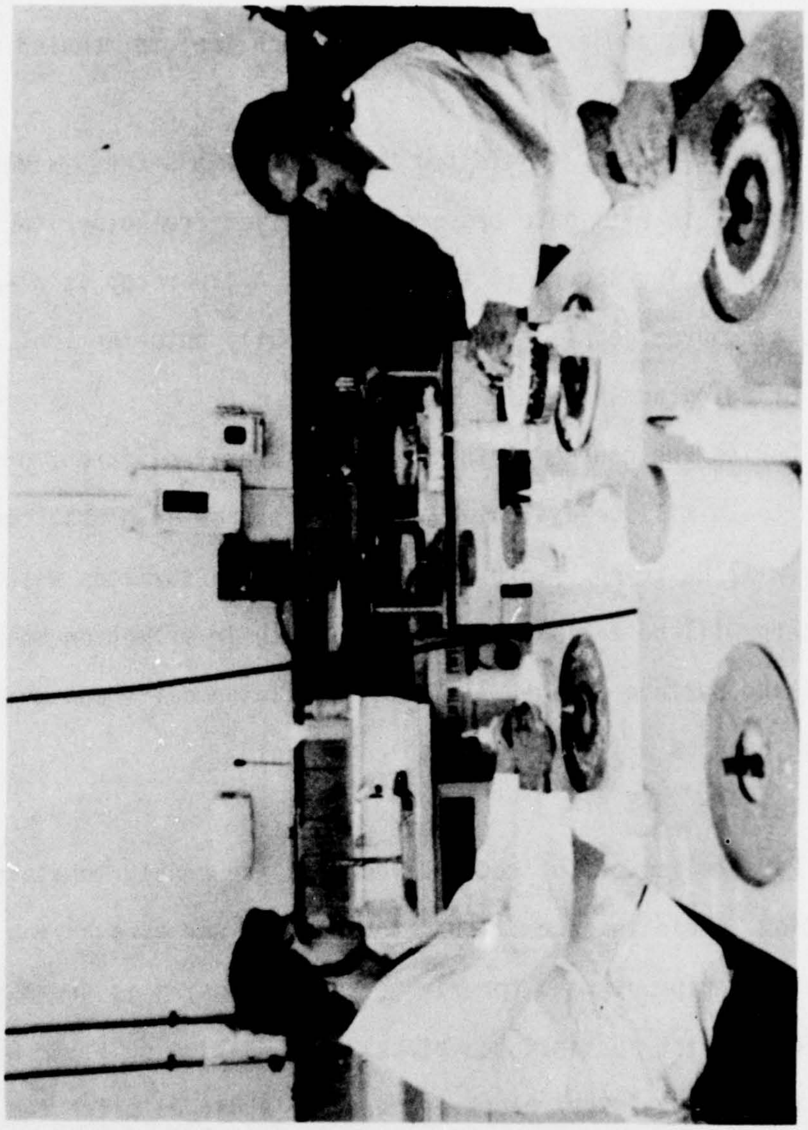


Figure 2 Laser Rod Polishing

drive motor allows the operator to select the proper rotation rate for the particular lap and grit being used and thus maintain the flatness of the lap. The table top dimensions are two feet deep by three feet wide. This size table permits the operator some workable counter space for this polishing or grinding powders when the eight inch tool is mounted on the spindle.

A clear plastic shield two feet high covers three sides of the table. This helps to eliminate cross contamination from other tables and lets the front open for access to the spindle. A clear top is also used to help stop air borne debris from falling directly onto the tool.

3.3 Grinding and Polishing Tools

During the course of this program several different polishing and grinding tools will be evaluated. Materials such as glass, cast iron and aluminum will be tried. Both plane surfaces and surfaces with a cross hatched pattern will be evaluated to determine their effect on material removal rate and surface damage. In this evaluation different grinding and polishing powders will be used with each tool.

3.4 Testing

Parallelism of the rod end faces is frequently monitored during fabrication. This is accomplished through the use of a Fizeau interferometer. The equipment used for single rod processing is shown in Figure 3. For working multiple rod blocks the positioning stage will be modified to handle the larger block. The stage provides pitch and yaw and vertical adjustment. These, plus rotation of the block and horizontal movement, allow for proper positioning of any rod within the block and nulling of the resulting fringe pattern.

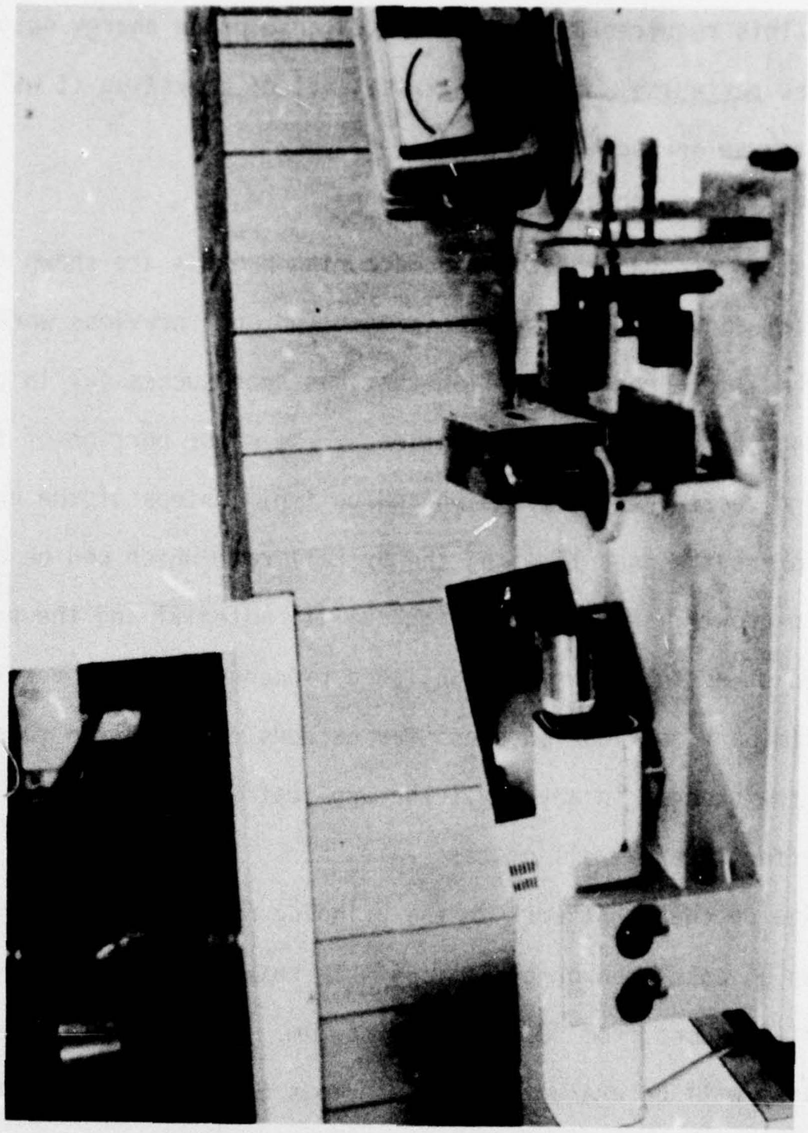


Figure 3 Fizeau Interferometer

The only other test equipment which will require modification is the laser system for damage tests on coatings. Testing to the level of 350 megawatts per square centimeter over the full rod aperture is required. This requires a laser system capable of an energy output of 0.660 Joules per pulse. To attain this level of operation it will be necessary to use an oscillator-amplifier system.

4.0 MANUFACTURING PROCESS

The steps of the proposed manufacturing process are shown in the Flow Chart of Figure 4. This process is based upon previous work on single and multiple rod fabrication that has been successful in producing rods meeting the required specifications. The major portion of this program is directed at the grinding and polishing steps of the operation. These steps are the ones limiting the overall rate which can be attained.

Boule growth, selection of high quality material and the preliminary fabrication steps follow well established procedures. The overall rate of these preliminary fabrication steps far exceeds the required rate and do not limit the process in any way. The application of coatings similarly will not effect the overall process rate.

It was decided that work in the grinding operation would start using Al_2O_3 grits on cast iron or glass laps. In this operation grit size is successively reduced from 20μm to 12μm to 5μm. In each step material removal rates will be evaluated. In previous experiments on multiple rod fabrication the overall grinding process has taken approximately 1.5 hours. The design goal of this program is to reduce this by 30-50%. If this cannot be readily accomplished using the above process, then other grit types such as silicon carbide and boron nitride, and other grit sizes will

Flow Chart of the Manufacturing Process

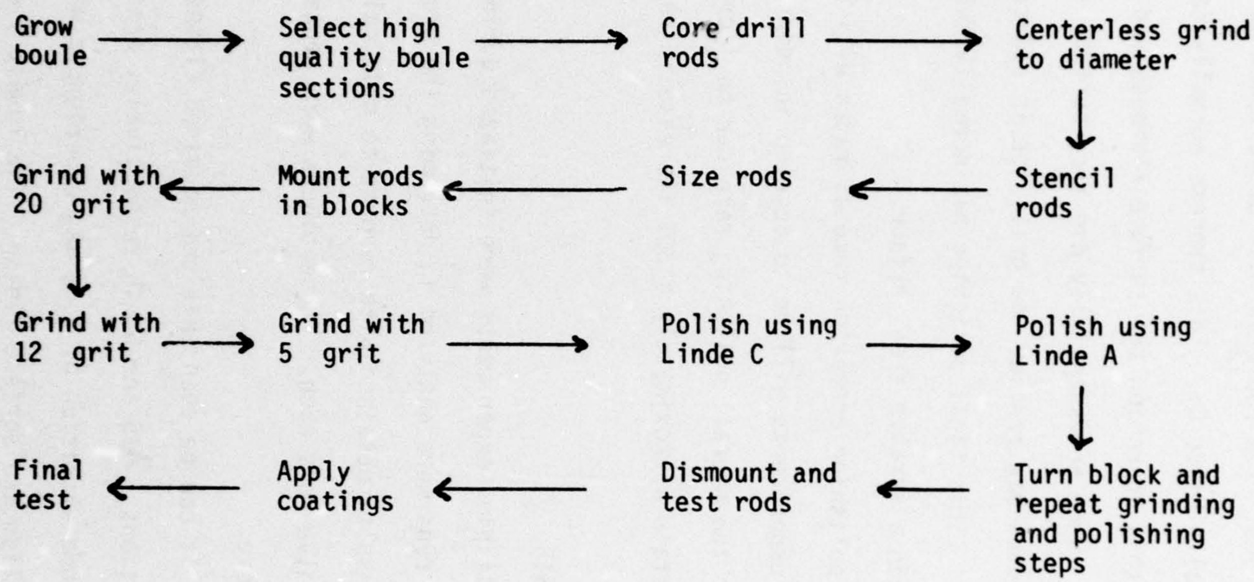


Figure 4

be evaluated.

The polishing approach chosen will use the basic system in operation for polishing single rods. The rod ends will be polished using a 1μm aluminum oxide (typically Linde C). This process normally takes approximately 1.5-2 hours. During this operation the surface flatness and finish are constantly monitored. When an essentially dig free surface is obtained and a few light scratches may remain, the grit size is reduced to 0.3 micron aluminum oxide. This final polishing has normally taken approximately one half hour to attain a scratch free surface.

Throughout the polishing operation removal rates will be evaluated. The purpose of these experiments will be to develop an understanding of the process such that the overall polishing rate can be increased. It is the design goal to attain approximately a 30% increase in rate of production.

5.0 DATA AND ANALYSIS

Although no polishing experiments were initiated during this quarter, the results of prior runs were analyzed in determing the process design. Table I lists the results obtained with respect to critical specifications on four blocks of twelve rods each. These blocks were processed using the process described above.

From the table it can be seen that the required flatness and perpendicularity specifications, $\lambda/5$ and 5 min. respectively, produced no problem. However, some attrition of rods was experienced with respect to rod end face parallelism and surface finish. The lowest yield was approximately 70 percent with respect to a scratch and dig free surface finish. Considering the program specification of a 20-5 surface finish

Table I

Results of Multiple Rod Fabrication Experiments

Number of Rods Which Meet Specification Below

.250" x 2.6" Rods	$\lambda/5$ Flat	20 sec. Parallel	2 min. Perpendicular	0-0 Surface Finish
Block No. 1	12	11	12	7
Block No. 2	12	12	12	10
Total	24	23	24	17
3mm x 50mm Rods				
Block No. 1	12	12	12	12
Block No. 2	12	10	11	12
Total	24	22	23	24

Notes: 1) Each block holds 12 rods.

and increased familiarity with the block polishing process, the 75 percent yield required by our polishing block (16 rods) should be readily attainable.

6.0 CONCLUSIONS

The design of a polishing fixture was chosen such that a symmetric surface will be presented for finishing. The fixture will hold the rods well within the required perpendicularity tolerance.

The polishing process chosen has successfully produced rods meeting the required tolerances. With the selected block design, yield problems should be minimized.

Rate requirements should be attainable with the process proposed. The rate increases required are moderate and should be realized through polishing rate experiments. New grit types and sizes can be evaluated if required.

7.0 PROGRAM FOR NEXT QUARTER

During this quarter, June 1, 1977 through August 30, 1977, initial experiments using the new polishing fixture will begin. Grinding and polishing rates will be analyzed as a function of type and size of polishing material used. Lap material and configuration will also be analyzed and its effect on rate determined. Work will continue on constructing the apparatus for the testing program.

8.0 IDENTIFICATION OF PERSONNEL

The following personnel contributed effort to the program this quarter.

DAVID J. DENTZ, Chief Engineer, is a 1963 graduate of Union College. Following graduation he worked for Pratt and Whitney Aircraft as an experimental engineer in a fuel cell development group. From 1964 to 1966 Mr. Dentz attended Lowell Technological Institute, receiving an M.S. degree in 1967. From 1966 to 1972 he attended New York University. Mr. Dentz joined Airtron in 1968 as a staff scientist specializing in measurement of optical properties of laser and electro optic materials. His work was particularly directed toward the establishment of quality assurance testing methods for laser materials. In 1974, Mr. Dentz was appointed Manager of the Czochralski Crystal Growth Facility. In that capacity he had the responsibility for production and development activities in that area. Work has included the development of growth and processing methods of garnet materials for high quality substrates. In 1976 he was appointed Chief Engineer of the Crystal Group directing all engineering efforts within that facility.

ROGER F. BELT, Research Director, is a 1950 graduate of Ohio State University. He received his M.S. in 1952 from Duquesne University and the Ph.D. in Physical Chemistry from the State University of Iowa in 1956. During 1950-1951 Dr. Belt was employed by Cities Service Oil Company as a petroleum chemist. In 1953 he worked for E.I. duPont, Nylon Division, on melt properties of polyester fibers. From 1956-1961, he was associated with the Physics Department of the B.F. Goodrich Research Center. During this interval he was in charge of structural programs on all types of high polymers. From 1961-1964 he was employed with the Crystal Solid State Division of Harshaw Chemical Company. Initial research efforts were on crystal growth and perfection of optical crystals. In 1964, Dr. Belt joined the Materials Laboratory of the Airtron Division of Litton Industries. His initial responsibilities included crystal growth, processing, structure and analysis. He developed new x-ray procedures for quality control in magnetic, laser and piezoelectric materials. During 1967 he was appointed Research Director of the Advanced Materials Laboratory. In that capacity he has directed major company and government sponsored research programs on ferrite materials, laser crystals, substrates, bubble domain garnets, flux growth, hydrothermal and Czochralski techniques, and crystal perfection studies.

IRVING J. LOWE, Manufacturing Manager, was graduated from Marist College in 1968 and received an M.B.A. in Industrial Administration from Fairleigh Dickinson University in 1973. From 1967 to 1970 Mr. Lowe was a project leader at the Ferroxcube Division of North American Philips. His work there included development of single crystal and polycrystalline magnetic material. In 1970 Mr. Lowe joined Airtron's Environmental Testing Laboratory, supervising all qualification, acceptance and process control testing. Mr. Lowe then became supervisor of Quality Assurance, assisting the manager of that department and was subsequently promoted to the position of Manager of Quality Assurance. He was responsible for all quality assurance activities at Airtron. Mr. Lowe then became Manager of Magnetic Products, with full administrative responsibility for production of a variety of solid state materials and devices. During 1976 Mr. Lowe was appointed Manufacturing Manager of Crystal Products, directing all manufacturing efforts within the crystal products group.

STEVEN TURNER, Supervisor, Rod and Crystal Fabrication, graduated from Middlesex County Vocational School as a Journeyman Machinist in 1969. He attended Rutgers State University from 1969 to 1970 and from 1975 to 1976 was enrolled in the Bell ¢ Howell Electronics Program. From 1961 to 1963 Mr. Turner was employed by Grant Tool as a shop foreman for the production of the third stage of the Minute Man Missile. From 1968 to 1974 Mr. Turner was lead man in the polishing and fabrication of laser crystals at Lambda Optics. During 1974 he was transferred to Lambda/Airtron and became supervisor in the rod and crystal fabrication department, developing procedures for the polishing of laser and electro optical crystals. Mr. Turner was instrumental in the design of the first fixture to house 12 laser rods for single surface polishing and the fixtures now in use at Lambda/Airtron for the fabrication of laser crystals.

JOHN A. O'NEILL, Senior Technician, was graduated from Monmouth College, West Long Branch, New Jersey, with an A.A. in Electronic Engineering in 1972 and a B.S. in Physics in 1974. During the summer of 1972 he was employed as an engineering aide at the U.S. Coast Guard Electronic Engineering Center, Wildwood, New Jersey. From 1974 to 1975 Mr. O'Neill was employed at Kay Elemetrics Corp., Pine Brook, New Jersey as an electronic technician. Mr. O'Neill has been employed at Lambda/Airtron since 1975, polishing and testing laser crystals.

Their contributions to the program this quarter were:

Engineers and Technicians	Hours
Dentz, D.	120
Turner, S.	40
Belt, R.	15
Lowe, I.	10
O'Neill, J.	10
Total Hours	195

9.0 REFERENCES

1. J.E. Geusic, H.M. Marcos, and L.G. Van Uitert, Appl. Phys. Letters, 4, 182 (1964).

2. R.F. Belt, R.C. Puttbach, J.R. Latore, and D. Dentz, Contract No. DAAB-05-71-C-2611, Final Report, Dec. 1972, "Production Engineering of Nd:YAG Laser Rods for Laser Illuminator Transmitters".

APPENDIX

ELECTRONICS COMMAND TECHNICAL REQUIREMENTS

SCS-507

NEODYMIUM DOPED YTTRIUM ALUMINUM GARNET LASER RODS

1. SCOPE

1.1 Scope.- This specification covers the detail requirements for single crystal <111> orientation, fine grind, neodymium doped yttrium aluminum garnet laser rods (Nd:YAG).

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of the invitation for bids, form a part of this specification to the extent specified herein:

SPECIFICATIONS

MILITARY

MIL-C-675	Coating of Glass Optical Elements (Anti-Reflection).
MIL-O-13830	Optical Components for Fire Control Instruments; General Specifications Governing the Manufacture, Assembly and Inspection of.

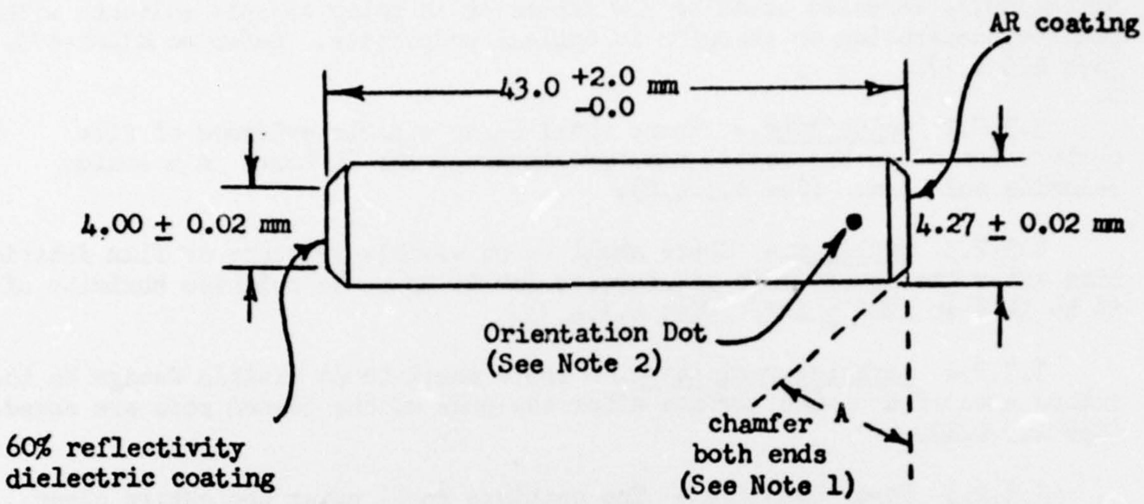
(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer. Both title and number or symbol should be stipulated when requesting copies.)

2.2 In the event of conflict between this document and the referenced ones, the detail requirements of this specification shall take precedence.

3. REQUIREMENTS

3.1 Neodymium doping level.- The laser rod material shall consist of single crystal, neodymium doped yttrium aluminum garnet. Doping of the neodymium shall be 1.0 to 1.3 atomic percent substituted for yttria in the crystal. (Dopant density range: 1.38×10^{20} to 1.8×10^{20} ions per cm^3). (See 4.5.1).

3.2 Dimensions.- The laser rod shall have the finished dimensions and tolerances as specified in figure 1. (See 4.5.2).



Notes: 1. Chamfer surface to be rough finish, 20 to 30 microinches. Chamfer angle A = 45° ± 5°.
2. The anti-reflection (AR) coated end of each rod shall be identified with a dot or similar mark located within 3 mm of rod end.

Figure 1

3.3 Optical properties.-

3.3.1 End surfaces.-

3.3.1.1 Surface quality.- End surfaces (figure 1) shall be polished to a surface quality of 20-5 (MIL-O-13830, Table I). (See 4.5.3.1).

3.3.1.2 Surface flatness.- The ends shall be flat to within 0.2 wavelength of sodium light (5898Å). (See 4.5.3.2).

3.3.1.3 Parallelism.- The ends shall be optically parallel to within 20 arc seconds. (See 4.5.3.3).

3.3.1.4 Perpendicularity.- The ends shall be perpendicular to the rod axis within 5 minutes of arc. (See 4.5.3.4).

3.3.2 <u>End surface coatings</u>.-

3.3.2.1 <u>Cleaning of surface coatings</u>.- The coatings shall be capable of withstanding repeated cleaning and immersion in polar organic solvents without peeling, separating or changing in optical properties. Refer to MIL-C-675. (See 4.5.4.1).

3.3.2.2 <u>Solubility</u>.- There shall be no visible evidence of film destruction after the coated rods are immersed for 24 hours in a sodium chloride solution. (See 4.5.4.2).

3.3.2.3 <u>Humidity</u>.- There shall be no visible evidence of film deterioration after the coated rods are exposed for 24 hours to relative humidity of 95 to 100% at 120° $\pm$ 4°F. (See 4.5.4.3).

3.3.2.4 <u>Abrasion resistance</u>.- There shall be no visible damage to the rubbed area of a coated surface after the ends of the coated rods are abraded. (See 4.5.4.4).

3.3.2.5 <u>Power handling</u>.- The coatings shall cover the entire clear aperture area of the surfaces and shall be capable of withstanding a minimum of 350 megawatts per square centimeter of laser power without degradation or change in optical characteristics. (See 4.5.3.6).

3.3.2.6 <u>Reflectivity</u>.-

3.3.2.6.1 As shown in figure 1, one end surface shall be dielectric coated to have 60% $\pm$ 3% reflectivity for 1.0644 micron radiation. (See 4.5.3.5).

3.3.2.6.2 The opposite end shall be anti-reflection coated with a low loss hard coating in accordance with MIL-C-675. This coating shall have a reflection loss no greater than 0.25% for 1.0644 micron radiation when in a medium with a refractive index of 1.0. (See 4.5.3.5).

3.3.3 <u>Strain</u>.- No more than one half (1/2) strain free fringes per 25.4 mm of rod length are allowable when analyzed by double-pass Twyman Green interferometry. (See 4.5.5).

3.4 <u>Marking</u>.- Each rod shall have a serial number such that individual rods can be identified. The AR coated end of each rod shall also be identified with a dot or similar mark in accordance with note 2, figure 1. (See 4.5.2).

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection.- Unless otherwise specified in the contract, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of inspection.- Inspection shall be classified as follows:

(a) First article inspection.

(b) Quality conformance inspection.

4.3 Test plan.- The contractor prepared Government-approved test plan, as cited in the contract, shall contain:

(a) Time schedule and sequence of examinations and tests.

(b) A description of the method of test and procedures.

(c) Programs, if automatic test equipment is used, including flow charts and block diagrams.

(d) Identification and brief description of each inspection instrument with date of most recent calibration.

4.4 Inspection requirements.-

4.4.1 First article inspection.- Prior to first article inspection, the following tests shall be performed: The Neodymium doping level (3.1 and 4.5.1) shall be performed on wafer samples from the boule. Failure of wafer samples is a failure of the entire boule. Test blanks prepared from wafer samples shall be coated with the rods in the coating batch. The test blanks shall be tested in the following sequence: Solubility (3.3.2.2 and 4.5.4.2), Humidity (3.3.2.3 and 4.5.4.3), Abrasion resistance (3.3.2.4 and 4.5.4.4), Reflectivity (3.3.2.6 and 4.5.3.5), and Power handling (3.3.2.5 and 4.5.3.6). Failure of any test blank in any test is a failure of all rods in that coating batch. First article tests on 10 rods shall consist of the tests specified in Table I and no failures shall be permitted.

Table I.- First article inspection

Inspection	Reqt Para	Test Para
Dimensions	3.2	4.5.2
Surface quality	3.3.1.1	4.5.3.1
Surface flatness	3.3.1.2	4.5.3.2
Parallelism	3.3.1.3	4.5.3.3
Perpendicularity	3.3.1.4	4.5.3.4
Cleaning of surface coatings	3.3.2.1	4.5.4.1
Strain	3.3.3	4.5.5

4.4.2 Quality conformance inspection.- Quality conformance inspection shall consist of tests specified for Group A inspection (Table II) and Group B inspection (Table III). The following shall apply:

(a) Prior to performing Group A inspection, the following inspections shall be done. The Neodymium doping level (3.1 and 4.5.1) shall be performed on wafer samples from each boule. Failure of wafer samples is a failure of the entire boule. Test blanks prepared from wafer samples shall be coated with the rods in the coating batch. The test blanks shall be tested in the following sequence: Solubility (3.3.2.2 and 4.5.4.2), Humidity (3.3.2.3 and 4.5.4.3), Abrasion resistance (3.3.2.4 and 4.5.4.4), Reflectivity (3.3.2.6 and 4.5.3.5), and Power handling (3.3.2.5 and 4.5.3.6). Failure of any test blank in any test is a failure of all rods in that coating batch.

Table II.- Group A inspection

Inspection	Reqt Para	Test Para	AQL
Dimensions	3.2	4.5.2	)
Surface quality	3.3.1.1	4.5.3.1	)
Surface flatness	3.3.1.2	4.5.3.2	) 1%
Parallelism	3.3.1.3	4.5.3.3	)
Cleaning of surface coatings	3.3.2.1	4.5.4.1	)

Table III.- Group B inspection

Inspection	Reqt Para	Test Para
Perpendicularity	3.3.1.4	4.5.3.4
Strain	3.3.3	4.5.5

4.4.2.1 Group B sampling.-

(a) Perpendicularity test - Two rods are randomly selected from each polishing batch. If both rods pass, all rods in the polishing batch are accepted. If both rods fail, all rods of the boule section will be rejected. If one rod fails, a second sample of two rods from the same boule section are selected. If both rods of second sample pass, all other rods of boule section are accepted. If one rod of second sample fails, all rods of boule section are rejected.

(b) Strain test - Two rods randomly selected from each boule section shall be examined for strain. If both rods pass, all rods of the boule section will be accepted. If both rods fail, all rods of the boule section will be rejected. If one rod fails, a second sample of two rods from the same boule section are selected. If both rods of second sample pass, all other rods of boule section are accepted. If one rod of second sample fails, all rods of boule section are rejected.

4.5 Test methods.-

4.5.1 Neodymium doping level.- Concentrations of neodymium in the laser rods shall be determined using x-ray emission spectroscopy. Wafer samples taken from regions of the boule immediately above and below the region where rods are to be fabricated, see figure 2, shall be subjected to analysis and comparison with standards. Equipment utilized shall include Picker X-Ray Corp., GE-XRD-5 or equivalent spectrogoniometers with LiF crystal analyzers and appropriate scintillation counters having pulse height discrimation capabilities. Neodymium densities shall be measured using Nd Lα line. Rod doping densities will be assigned based on the average of the values determined for the sample immediately above the rod and immediately below the rod, figure 2. If not already available to the contractor, he shall prepare appropriate standards for accomplishing measurements. If prepared by the contractor, the standards shall be formed in accordance with established laboratory procedures which serve to insure homogeneity of the standards and densities approaching that of a single crystal. High density powder pellets or polycrystalline standards may be considered with the above boundaries. In determining the Nd concentrations of the calibration samples, comparison to all methods will be made: wet chemistry analysis, x-ray analysis and/or optical density measurements. The standards shall be maintained during the course of the contract and secondary standards utilized if desired or necessary.

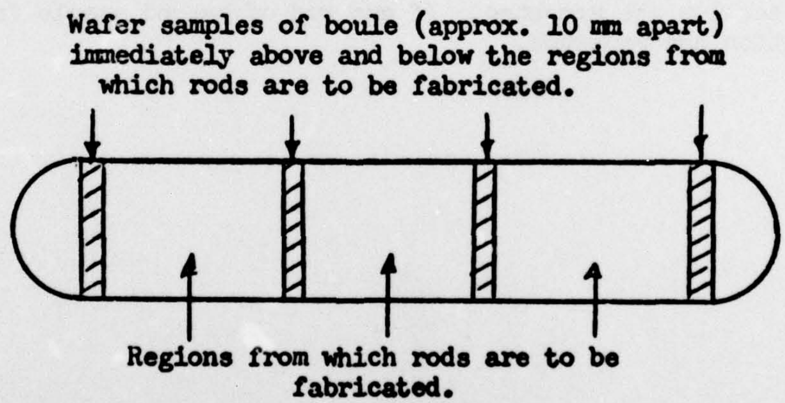


Figure 2

4.5.2 Dimensions.- Rod dimensions shall be measured using suitable mechanical, electrical or optical devices with appropriate care being exercised as to not damage the face surfaces. The rod shall be inspected for presence of required serial number and orientation dot.

4.5.3 End surfaces.-

4.5.3.1 Surface quality.- Surface quality of each rod end shall be determined in accordance with MIL-O-13830.

4.5.3.2 Surface flatness.- Surface flatness of each rod end shall be established using a master optical flat of at least 1.0 inch in diameter and certified flat over that diameter to 0.1 wavelength for 5898Å radiation.

4.5.3.3 Parallelism.- End face parallelism of each rod shall be established using a Fizeay interferometric device with a HeNe (6328Å) source. Conversion from fringe count to arc seconds will be accomplished. Final parallelism will be determined on unstressed rods.

4.5.3.4 Perpendicularity.- End face - rod axis perpendicularity of each rod will be established using a suitably calibrated auto-collimator in conjunction with a mechanical mounting apparatus for rotating the rods through 360°. Since parallelism has been established, one end face is aligned with the auto-collimator and zeroed. The rod run-out is established by rotating the rod through 360° about its axis and using the reticle of the collimator to determine the magnitude. Final perpendicularity will be determined on unstressed rods.

4.5.3.5 Reflectivity.- During rod end-face coating, suitable test blanks prepared from wafer samples shall be simultaneously coated for use in determining the reflectivity values of the rod coatings. Measurements will be performed on a Cary 14 Spectrometer or equivalent.

4.5.3.6 Power handling.- Prior to the power handling test, the end surface coatings shall meet all reflectivity specifications. The test blanks prepared from wafer samples will be utilized to ascertain the power handling capabilities of the coatings for 1.06 micron radiation. The anti-reflection coating shall meet MIL-C-675. The coatings shall be tested to determine if they can withstand a minimum of 350 megawatts per square centimeter of laser power without degradation or change in optical characteristics. The appropriate coating under test will be inserted into the beam path of a "Q" switched

laser operating at a wavelength of 1.06 microns, at a position such that a power density of 350 megawatts per square centimeter is incident on the coating. The area under test shall be equivalent to the rod polished aperture and be fully illuminated with the "Q" switched pulse. The laser pulse width shall be 15 ± 5 nanoseconds full width at half maximum which places an average energy per pulse of 0.660 joules on the test laser. The samples after irradiation shall meet the specifications for reflectivity cited in 3.3.2.6 and exhibit no burn spots or crazing or signs of the surface coating lifting from the substrate.

4.5.4 <u>End surface coatings</u>.-

4.5.4.1 <u>Cleaning of surface coatings</u>.- Each rod shall be immersed in ethyl alcohol, methyl alcohol and acetone. Once the rod is removed and allowed to dry it shall be re-immersed. Each rod shall receive a minimum of 6 immersions and dehydrations in each of the three solvents. Upon analysis, there should be no evidence of peeling, separating or changing in optical properties.

4.5.4.2 <u>Solubility</u>.- Each blank shall be subjected to the solubility test specified in 4.6.8 of MIL-C-675.

4.5.4.3 <u>Humidity</u>.- Each blank shall be subjected to the humidity test specified in 4.6.9 of MIL-C-675.

4.5.4.4 <u>Abrasion resistance</u>.- Each blank shall be subjected to the abrasion resistance test specified in 4.6.11 of MIL-C-675.

4.5.4 <u>Strain</u>.- Each rod will be examined in a double pass Twyman Green interferometer using a HeNe (6328Å) laser source. The rods shall be unstressed in mount. The fringe per inch value shall be determined neglecting edge fringing effects.

5. PREPARATION FOR DELIVERY

5.1 The contractor shall package the rods in a suitable container to preserve the end face conditions and the general integrity of the rods during shipment and storage.

6. NOTES

6.1 A fine grind outside surface roughness is defined as being in a range of 20 to 30 microinches finish.

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